# Three-Dimensional Carpal Kinematics after Carpal Tunnel Release

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## Abstract

**Background** Carpal tunnel release (CTR) has been shown to change carpal arch morphology. However, the effect of CTR on the three-dimensional kinematics of the carpal bones has not been demonstrated.

**Purpose** This study examined whether release of the transverse carpal ligament (TCL) would alter the three-dimensional kinematics of the carpus, specifically the bony attachments of the TCL.

**Methods** The in vitro kinematics of the carpus was studied in five fresh-frozen cadaveric wrists before and after CTR using three-dimensional computed tomography. The specimens were evaluated in three positions: neutral, 60 degrees of flexion, and 60 degrees of extension.

**Results** The data indicate that carpal arch width increases significantly in all positions after CTR as measured between the trapezium and hamate. Second, the trapezium–hamate distance increases in both a translational and rotational component after CTR. Additionally, the pisiform rotates away from the triquetrum after CTR.

**Conclusions** Carpal kinematics is significantly altered with a CTR, especially on the ulnar side of the wrist.

**Clinical Relevance** Although the kinematic changes are small, they may be clinically significant and potentially responsible for pillar pain or postoperative loss of grip strength.

**Keywords**
- carpal arch width
- carpal kinematics
- carpal bone contours
- carpal tunnel release
- transverse carpal ligament

Approximately 2 million new cases of carpal tunnel syndrome (CTS) are diagnosed yearly in the United States, making it one of the most common orthopedic problems.[1] Annually, 500,000 carpal tunnel releases (CTRs) are done in the United States with the majority of patients enjoying symptomatic relief.[2] However, a significant number of patients continue to have postoperative complications, such as pillar pain, loss of grip strength, or recurrence of median nerve neuropathy.[3]

CTR involves the complete division of the transverse carpal ligament (TCL) which acts as a pulley for the flexor tendons and helps maintain the concavity of the normal carpal arch. Several studies have examined the morphological changes on the carpus after CTR. Gartsman et al quantified postoperative widening of the carpal arch after CTR using standard carpal tunnel radiographs; the carpal arch width (CAW) had a mean increase of 10.4% or 2.7 mm, which correlated with a subsequent loss of grip strength.[4] Garcia-Elias et al also demonstrated an increase of 11% in the CAW, measured between the trapezium and hook of hamate, after release of the TCL.[5] Richman et al utilized pre- and postoperative magnetic resonance imaging (MRI) to show an increase in carpal canal volume, a 6.3% increase in CAW, and anterior median nerve displacement after CTR.[6] Viegas et al noted a 1.7 mm increase in CAW 10 days after surgery, as well as a 7% increase in canal

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volume.[7] Similarly, Ablove et al found a volume increase of 23% in the carpal canal postoperatively.[8]

All studies to date demonstrate alterations in the carpus or carpal kinematics after CTR in two dimensions, using standard radiographs, computed tomography (CT) scan, or MRI. This study is the first to examine the carpus and carpal kinematics in three dimensions. We hypothesized that release of the TCL not only increases the CAW, but also changes the relationship of the bony attachments of the TCL. The purpose of this study was to demonstrate a three-dimensional change in the carpal kinematics after release of the TCL.

## Materials and Methods

### Subjects, Image Acquisition, and Surgical Methodology

Based on 200 hands from seven studies analyzing CAW after CTR in the literature, a power analysis was conducted using a power of 0.8 and an $\alpha$ value of 0.05, which determined five specimens were needed to demonstrate a significant change. Five fresh-frozen cadaveric wrists were used in this study. Radiographs were taken to eliminate any wrists that had any carpal pathology prior to beginning the study. All were thawed at least 8 hours prior to testing. The wrist extensors (extensor carpi radialis longus and brevis, and extensor carpi ulnaris) and the finger and thumb flexors (flexor digitorum superficialis, flexor digitorum profundus, and flexor pollicis longus) were dissected and isolated prior to placing the wrist in the custom jig. They were then loaded with 5 pounds using a locking 2–0 Ethibond suture in the proximal six tendon ends to reproduce the forces that are present in the wrist.[5] All testing was performed with these tendons loaded. The specimen was then mounted in the custom-designed jig (►**Fig. 1**).

**Fig. 1** Custom-designed jig with goniometer and mounted fresh-frozen cadaveric specimen. Wrist extensors and finger and thumb flexors isolated and loaded with 5 pounds at the pulley end of the jig.

The specimens were imaged using a CT scanner (GE Hi-Speed Advantage; GE Medical, Milwaukee, WI) in neutral, 60 degrees of flexion, and 60 degrees of extension prior to the CTR. The jig was loaded on the front end of the scanner and was scanned by consecutive 1.0 mm slices of the carpus, from the distal radius to the proximal metacarpals. Images were reconstructed with a voxel size ranging from 0.2 mm $\times$ 0.2 mm $\times$ 1.0 mm to 0.9 mm $\times$ 0.9 mm $\times$ 1.0 mm.

A standard mini-open CT with the specimen still mounted in the jig was performed.[9,10] The wrist and finger flexor and extensor muscles were cycled 10 times each after the CTR, and the specimen was then rescanned in neutral, 60 degrees of flexion, and 60 degrees of extension. A post-CT scan dissection of the palmar arch was conducted to ensure complete release of the TCL proper, aponeurosis, and distal antebrachial fascia in all five specimens.

### Image Processing and Bone Analysis

Utilizing CT scan images, the carpal bones from each wrist, both pre- and post-CTR, were segmented. Carpal bone contours were mapped using commercially available computer software (Analyze; Mayo Foundation, Rochester, MN; Geomagic; Raindrop, Durham, NC), and then the bone volume, inertial axis, and bone centroid (geometrical center of a solid object) could be calculated using special software (Matlab; Mathworks, Natick, MA).[11] Statistical comparisons were made with Student *t*-tests; *p*-values less than 0.05 were considered significant.

## Results

### Effect of CTR on Carpal Arch Width

The CAW was measured before and after CTR in neutral, 60 degrees of flexion, and 60 degrees of extension. Prior to releasing the carpal tunnel, there was a 1.5 mm ($p < 0.05$) difference between 60 degrees of wrist flexion and 60 degrees of extension (►**Fig. 2**). There was no significant difference between wrist flexion and neutral, or neutral and wrist extension. The CAW increased significantly between pre- and post-CTR in neutral (average, 1.81 mm; $p < 0.02$), 60 degrees of flexion (average, 0.81 mm; $p < 0.003$), and 60 degrees of extension (average, 1.25 mm; $p < 0.003$) (►**Fig. 3**). There was no significant difference in ligament length (CAW) between 60 degrees of flexion and neutral, neutral and 60 degrees of extension, or 60 degrees of flexion and 60 degree of extension.

### Effect of CTR on Centroid Spacing and Rotation

The centroid spacing between the trapezium and the hamate increased significantly between pre- and post-CTR (average of 0.4 mm) in neutral ($p < 0.035$), 60 degrees of flexion

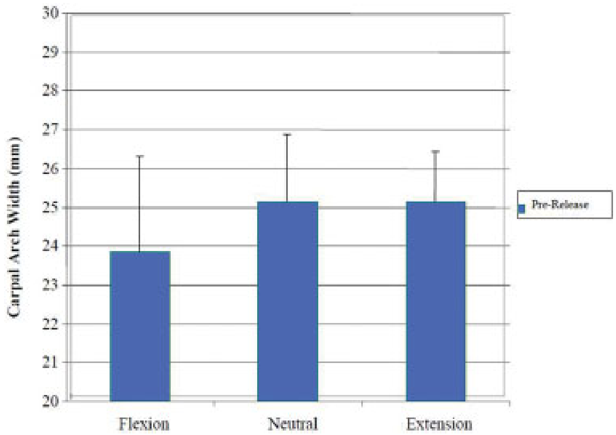


**Fig. 2** Carpal arch width decreased significantly ($p < 0.05$) between 60 degrees of extension and 60 degrees of flexion prior to release of the transverse carpal ligament. No significant difference existed between 60 degrees of flexion and neutral, or neutral and 60 degrees of extension.

($p < 0.02$), and 60 degrees of extension ($p < 0.03$) (►**Fig. 4**). Interestingly, no significant differences were found in centroid spacing between pre- and postrelease in the scaphoid and pisiform, which serve as an insertion site for the TCL, or the lunate, triquetrum, or trapezoid in any of the positions.

Centroid rotation of the hamate and trapezium relative to a fixed capitate increased significantly from prerelease neutral to postrelease neutral ($p < 0.05$) (►**Fig. 5**). The hamate rotated ~4.5 degrees, while the trapezium only rotated 2.25 degrees. No significant rotation between pre- and postrelease was evident in the scaphoid, lunate, triquetrum, pisiform, or trapezium relative to the capitate in any of the positions.

### Effect of CTR on Ulnar-Sided Carpal Relationships

After CTR, the pisiform rotated outwardly relative to the triquetrum by 3.8 degrees ($p < 0.001$) from 60 degrees of flexion to 60 degrees of extension. No significant rotational changes were evident in the hamate–pisiform or hamate–triquetral relationship from 60 degrees of flexion to 60 degrees of extension. The pisiform centroid also displayed a trend toward displacement away from the triquetrum by 0.13 mm; however, this was not significant ($p < 0.0995$) (►**Fig. 6**).

## Discussion

This study was performed to determine if CTR altered three-dimensional kinematics in the carpus. Initial results demonstrated a significant increase of the CAW after CTR in each position, which confirmed previous work in the literature.[4,6–8,12,13] Centroid spacing significantly increased between the hamate and trapezium. No other carpal bones demonstrated a significant change in centroid spacing after CTR. Ulnar-sided changes were exemplified by greater rotation of the hamate compared with the trapezium relative to the capitate after CTR, as well as significant rotation of the pisiform away from the triquetrum by an average of $3.83 \pm 1.14$ degrees. The pisiform centroid displayed a trend toward rotation away from the triquetrum, although this was not significant.

The major mechanism for increasing centroid spacing is rotation in three dimensions, as well as a translational component. The combination of increased CAW (1.25 mm) with increased trapeziohamate centroid distance of lesser magnitude (0.4 mm) implies that the hamate and trapezium are rotating apart from one another. The bones are not simply moving their centroids away from one another (not pure translation), but maintain a rotational component as well.

CTR has a statistically significant effect on three-dimensional carpal kinematics, especially on the ulnar side of the wrist. However, the kinematic changes are small and therefore may not be clinically significant. An in vivo carpal tunnel study may reveal an etiology for ulnar-sided postoperative complications such as pillar pain and loss of grip strength.

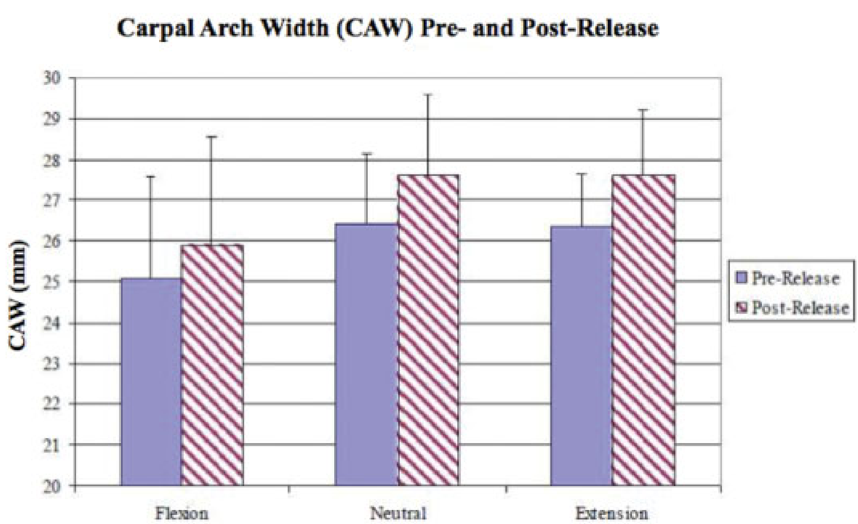


**Fig. 3** The carpal arch width increased significantly between pre- and postrelease in neutral, 60 degrees of flexion, and 60 degrees of extension ($p < 0.02$, 0.003, and 0.003, respectively). No significant difference was found between 60 degrees of flexion and neutral, neutral and 60 degrees of extension, or 60 degrees of flexion and 60 degrees of extension.

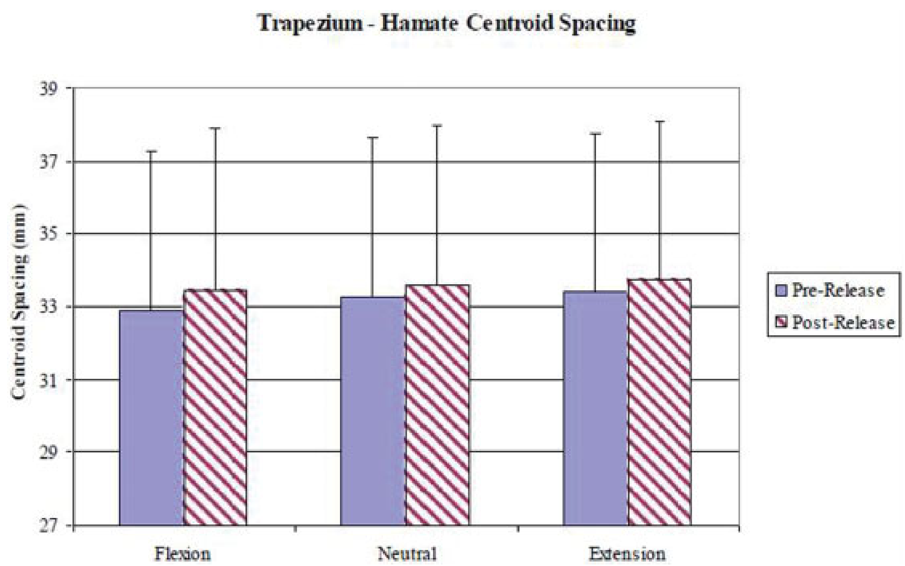


**Fig. 4** Centroid spacing between the hamate and trapezium was significant after CTR in neutral ($p < 0.035$), 60 degrees of flexion ($p < 0.02$), and 60 degrees of extension ($p < 0.03$). No significant differences were found between any other carpal bones after CTR.

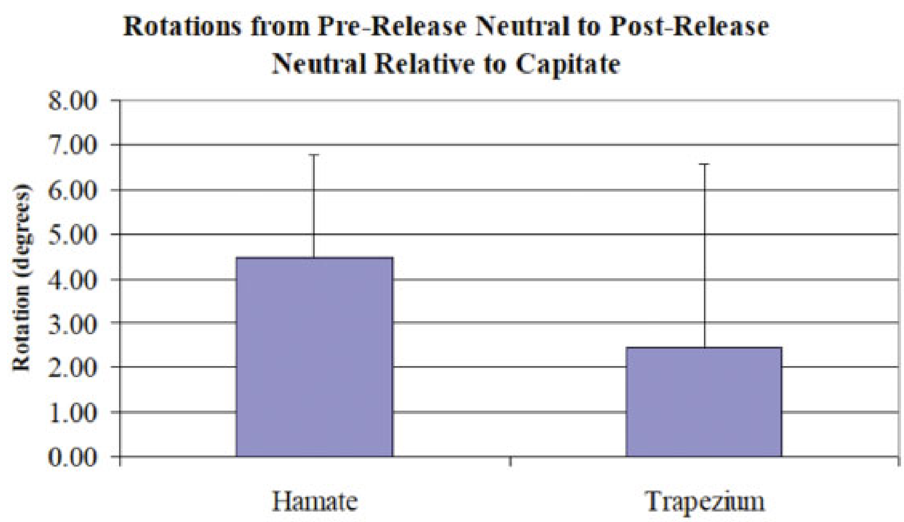


**Fig. 5** Centroid rotation relative to a fixed capitate increased significantly ($p < 0.05$) at the hamate and trapezium from prerelease neutral to postrelease neutral.

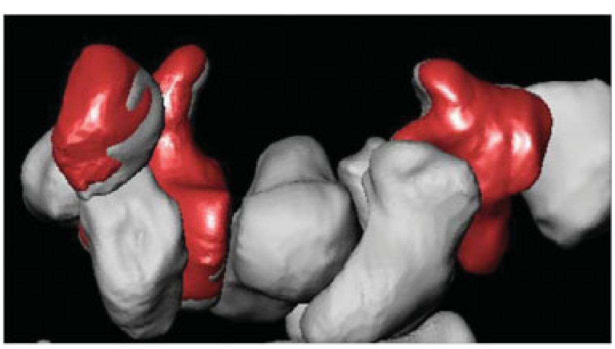

**Fig. 6** Three-dimensional illustration of the carpus pre- and postcarpal tunnel release. Gray shading represents the carpus precarpal tunnel release, while red is the postrelease position. The postrelease red has both a translational and rotational component, especially the pisiform and pisotriquetral articulation. Thus, the carpal arch width is not only increased, but also rotating.

There are several limitations of this cadaveric study. First, prior to conducting this study, we performed a power analysis based on 200 hands from seven studies analyzing CAW after CTR in the literature. Based on this power analysis, we determined that five specimens were needed to demonstrate a significant change in carpal kinematics. Given the interspecimen variability, we encountered higher standard deviations than we anticipated. Therefore, as a result of these higher than anticipated standard deviations, our study is underpowered and must be interpreted with that in mind. This study serves as a preliminary investigation of the three-dimensional kinematics after TCL transection. Future investigations will require a higher number of specimens to achieve an appropriate power. Second, we attempted to recreates physiologic forces across the wrist by loading individual muscles that cross the wrist. However, in vivo forces are not constant and vary significantly with varying degrees of flexion and extension of the wrist. Therefore, an in vivo analysis of carpus motion could more accurately illustrate the three-dimensional sequelae of CTR.

Note
This investigation was performed at Department of Orthopaedics, Rhode Island Hospital/The Warren Alpert Medical School of Brown University, Providence, Rhode Island.

Conflict of Interest
None.

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